Validation and Calibration of the Actical Accelerometer in Preschool Children

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ABSTRACT

PFEIFFER, K. A., K. L. MCIVER, M. DOWDA, M. J. C. A. ALMEIDA, and R. R. PATE. Validation and Calibration of the Actical Accelerometer in Preschool Children. *Med. Sci. Sports Exerc.*, Vol. 38, No. 1, pp. 152–157, 2006. **Purpose:** Decreased physical activity (PA) is likely a contributor to the rising prevalence of obesity in children. Lack of valid and acceptable measures of PA has been an issue in studies involving young children. The Actical accelerometer is a promising tool for measurement of PA in young children. The purpose of this study was to calibrate and validate the Actical accelerometer for use with 3- to 5-yr-old children. **Methods:** Eighteen preschool children wore an Actical accelerometer and a Cosmed portable metabolic system during a period of rest, while performing three structured activities in a laboratory setting (used for calibration), and during 20 min each of unstructured indoor and outdoor activities at their preschool (used for cross-validation). Expired respiratory gases were collected, and oxygen consumption was measured on a breath-by-breath basis. Accelerometer data were collected in 15-s intervals. **Results:** For the accelerometer calibration, the correlation between $\dot{V}O_2$ and counts was r = 0.89 across all activities. The calibration equation established was $\dot{V}O_2$ = counts·15 s^{-1} (0.01437) + 9.73 (R^2 = 0.96, SEE = 3.02). The cut-point for moderate activity (20 mL·kg^{-1}·min^{-1}) was 715 counts·15 s^{-1} (sensitivity 97.2%, specificity 91.7%), and the cut-point for vigorous activity (30 mL·kg^{-1}·min^{-1}) was 1411 counts·15 s^{-1} (sensitivity 98.2%, specificity 61.1%). For the cross-validation, the intraclass correlation coefficient was R = 0.59 and the Spearman correlation coefficient was R = 0.80 ($P < 0.001$) between measured and predicted $\dot{V}O_2$. Percentage of agreement, kappa, and modified kappa for moderate activity were 0.73, 0.40, and 0.46, respectively. For vigorous activity, the same measures were 0.85, 0.26, and 0.71, respectively. **Conclusion:** The Actical accelerometer is a valid tool for measuring PA in young children. **Key Words:** PHYSICAL ACTIVITY, MEASUREMENT, COUNT CUT-POINTS, INDIRECT CALORIMETRY

Prevalence of obesity in the United States has been on the rise in recent decades in children and adults (20,18). Among young children (ages 4 and 5), the prevalence of overweight increased from 5.8% in 1971–1974 to >10% in 1988–1994 (11). Between 1999 and 2002, the prevalence of overweight was up to 10.3% in 2- to 5-yr old children (6). Reduced physical activity is likely a major contributor to the rise in obesity levels (21); however, few physical activity studies have focused on this age group.

Several methods are available for measuring physical activity in children and adolescents. The most appropriate method varies by research question, because each method has its own strengths and weaknesses. Reliability, validity, feasibility, and cost of the methods vary widely. Most large-scale, population-based research studies have used self-report measures of physical activity due to feasibility and cost concerns. However, self-report measures have limitations that need to be carefully considered when used with children and adolescents. It is well known that young children are unable to validly self-report their physical activity (2,16), and surrogate reports by parents and other adults have limited validity (15).

For this reason, combined with the fact that accelerometers provide information on frequency, intensity, and duration of activity in a tamper-resistant casing (4), researchers now prefer accelerometry for assessment of physical activity in children and adolescents. Accelerometry does have limitations, such as underdetection of some non–weight-bearing activities and inability to detect the increase in energy expended while moving uphill. More information about accelerometry is needed in order to advance its use in physical activity studies involving children and adolescents, especially because the instrument must be calibrated for the specific population in which it is applied.

The Actical accelerometer (Mini-Mitter; Bend, OR) is the smallest accelerometer available, and is also water resistant; these two characteristics make it attractive for population-based research. In addition, it uses an omnidirectional sensor that may capture some activities not typically well assessed by accelerometry. There are limited data available regarding the reliability and validity of the device (7,13); however, unpublished data from our research group has shown an acceptable interinstrument reliability coefficient (R = 0.92). The Actical has not yet been tested in young children using a metabolic criterion measure of physical activity. The primary purpose of this study was to calibrate

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Submitted for publication March 2005.
Accepted for publication July 2005.

0195-9131/06/3801-0152/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/01.mss.0000183219.44127.e7

the Actical accelerometer for use with 3- to 5-yr-old children using a concurrently measured rate of energy expenditure (indirect calorimetry) as the criterion measure of physical activity. In addition, we conducted a cross-validation using a metabolic criterion while children performed unstructured physical activity in outdoor and indoor settings.

METHODS

Subjects. Eighteen preschool children, ages 3–5 yr (4.4 ± 0.7 yr), were recruited from a preschool in Columbia, SC. The sample was 61% female and included mostly African American (89%) children. The sample varied in physical characteristics, and none of the participants had any physical limitations that restricted their participation in physical activity. The protocol for this study was approved by the University of South Carolina institutional review board and by the preschool's director. Before participation, the parent or guardian of each child provided written informed consent.

Age and ethnicity were provided by each participant's parent or guardian on the consent form. Height was measured to the nearest 0.1 cm using a portable stadiometer (Shorr Productions, Olney, MD). Weight was measured to the nearest 0.1 kg using an electronic scale (Seca, Model 770, Hamburg, Germany). The average of two measurements was used for both height and weight.

Study design. Data collected in this study were cross-sectional, and participants were assessed over the course of three visits. The calibration visit required a parent or guardian to bring the child to a laboratory setting so that he or she could perform a session of rest and three structured activities (two walking speeds and one jogging speed). The cross-validation visits required the data collection staff to go to the participants' preschool so that each child could perform indoor and outdoor unstructured activities.

Accelerometry. The Actical accelerometer (Mini Mitter) has an omnidirectional sensor and is capable of measuring movement in one plane. The sensor functions via a cantilevered rectangular piezoelectric bimorph plate and seismic mass, and it is capable of detecting movements in the 0.5- to 3-Hz range. Voltage generated by the sensor is amplified and filtered via analog circuitry. The amplified and filtered voltage is passed into an analog to digital converter, and the process is repeated 32 times per second (32 Hz). The resulting 1-s value is divided by four, then added to an accumulated activity value for the epoch. The Actical is the smallest accelerometer available (28 × 27 × 10 mm, 17 g) and is water resistant. For the present study, the monitors were initialized to save data in 15-s intervals (epochs) to detect the spontaneous activities of 3- to 5-yr-old children. Children wore the accelerometers on the right hip (anterior to the iliac crest), secured with an elastic belt.

Metabolic measures. Expired respiratory gases were collected, and oxygen consumption ($\dot{V}O_2$) was measured on a breath-by-breath basis using the Cosmed portable metabolic system (Model K4b2, Rome, Italy). The unit is a lightweight system (925 g) that was worn on the back via a harness system. Before each measurement session, the unit was calibrated with standard gases. The system has been validated previously (10). Because of the effect of digestion on metabolism, parents and preschool teachers were asked not to give the child food within the 2-h period before each testing session.

Structured activities. Structured activities were performed in laboratory and gymnasium settings. For the resting session, each child was asked to sit comfortably in a reclining chair while watching a popular children's movie or cartoon. During the resting measurements, only the mask from the portable metabolic analyzer was worn, with the rest of the Cosmed unit placed on a surface next to the child. The participants were wearing accelerometers for this portion of the testing. The test did not begin until the child was situated and still and the metabolic readings were stabilized. Children were monitored for 10 min in the resting state, but it was not possible to obtain a value for true resting metabolic rate (RMR).

A researcher paced each child for 5 min at each of three different speeds as he or she walked or jogged on level ground. The child was instructed to stay by the researcher's side throughout each test so that steady state could be achieved for each activity. If a child could not keep up with the pace, he or she was asked to keep moving at his or her own speed. Split times were recorded to determine the real speed at which children completed the test, if necessary. Two walks were completed, a slow walk at 2 mph and a brisk walk at 3 mph. The jogging session was performed at 4 mph. Although speed could possibly have been better controlled using a motorized treadmill, the research team was concerned about the ability of young children to perform the various speeds on a treadmill. Further, it was not likely that any of the children had ever been habituated to treadmill exercise. By having children walk on their own volition, we removed any added metabolic effects that poor economy could have had on the testing.

Between structured activities, the child was given time to rest and recover from the exercise. Throughout the testing process, each child was verbally encouraged to maintain the pace and complete the 5 min of activity. At the completion of each test (speed), the child received a small incentive, which consisted of his or her choice of items such as a sticker, bouncy or inflatable ball, plastic ring, toy airplane, or bubbles. If any event requiring the child to stop for a length of time occurred during the testing session, the test was terminated and a second trial was attempted.

Unstructured activities. Each child participated in his or her choice of activities for 20 min each in both an indoor and an outdoor setting at the preschool. Children participated in normal activities with their classmates; however, in situations where other children were not present, a researcher participated with the child in his or her choice of activity. The children wore the Cosmed unit and accelerometer the entire duration for each session, such that counts and $\dot{V}O_2$ could be simultaneously measured throughout. Typical indoor activities included playing with blocks, reading, computer time, sociodramatic play, and music and movement play. Outdoor sessions typically included climbing, swinging, digging, playing with balls or other objects, and running or chasing. Bouts of activity lasted 4–6 min, and the child was then instructed to select something else until 20 min had passed. Attempts were made to have the children participate in a range of physical activity levels while inside and outside. The goal was to simulate free-living activities as closely as possible, because the ultimate purpose of using the accelerometer is to estimate energy expenditure during free-living activities.

Data reduction. For both the calibration and cross-validation analyses, $\dot{V}O_2$ data were summarized over 1-min intervals to smooth the effects of respiratory rate on ventilatory parameters. Accelerometer data were summarized by averaging the four 15-s counts over each minute. For the calibration analysis, minutes 8 and 9 from the rest and minutes 3 and 4 from each of the three speeds were used to summarize the data. Data from minute 5 were not used because children sometimes did not complete all 5 min of activity. Accelerometer counts and $\dot{V}O_2$ were averaged over the 2 min of data collection for each of the four activities. For the cross-validation analysis, 8 of the 40 min of observation were randomly chosen to be summarized; 4 min were from indoor activities, and 4 min were from outdoor activities. The minutes were not necessarily consecutive, and they did not necessarily represent steady state. Because the purpose of the cross-validation was to test the established calibration equation and cutoffs in free-living situations, we felt it was important to vary the intensity of the activities performed but not to prescribe the activities *per se*.

Statistical analysis. For the calibration analysis, means and SD for $\dot{V}O_2$ and accelerometer counts during the rest and structured activities were calculated. These calculations were performed for the total group.

Random-coefficients models using PROC MIXED in SAS (Version 8.2, SAS Institute, Cary, NC) were used to explore the relationship between $\dot{V}O_2$ and accelerometer counts. Intercepts and slopes were fitted for each subject and then an overall regression line was calculated. In addition to accelerometer counts for prediction of $\dot{V}O_2$, other variables were considered both one at a time and in a multivariate model. The variables included gender, age, height, quadratic terms for age and height, and interactions of the variables with accelerometer counts. The models were compared and assessed using goodness of fit statistics (8,9). After finalization of a proposed model, sensitivity and specificity values were calculated by comparing the $\dot{V}O_2$ values and counts obtained from the equation and grouping the activities. This calculation was performed between rest and slow walk for a moderate-to-vigorous physical activity (MVPA) cut-point and between all other activities and jogging for a vigorous physical activity (VPA) cut-point.

For the cross-validation analysis, several methods were used to assess the agreement between $\dot{V}O_2$ as measured by the Cosmed and $\dot{V}O_2$ from the prediction equation during unstructured activity. Intraclass, Spearman, and Pearson correlations were calculated. Percentage of agreement, kappa, and modified kappa (9) were obtained after dichotomizing the data at the $\dot{V}O_2$ estimated for the MVPA and VPA cut-points.

RESULTS

Calibration. The mean age of participants was 4.4 yr (SD = 0.7, range 3.4–5.7), and they had a mean height of 105.1 ± 7.5 cm, mean weight of 18.8 ± 5.6 kg, and mean body mass index of 16.7 ± 2.6 $kg \cdot m^{-2}$ (range 13.7–24.5). The average speeds children attained for the slow walk, brisk walk, and jog were 2.0, 2.9, and 3.8 mph, respectively. Most of the children performed the two walking speeds very closely to the prescribed speeds; there was more variation in jogging speed (range 3.1–4.1 mph), with 11 of the 18 participants not attaining exactly 4.0 mph. Figure 1 shows $\dot{V}O_2$ data and Actical counts for each subject for rest and the three structured activities. The Pearson correlation coefficient between $\dot{V}O_2$ and counts across all activities was 0.89 (Spearman = 0.90).

$\dot{V}O_2$ values as measured by the Cosmed during rest and during the three structured activities are shown in Table 1. Actical counts for each of the activities are also shown. Goodness-of-fit indices from the model with only Actical counts was $R^2 = 0.959$ (SEE = 3.02) and Akaike information criterion (AIC) of 435.9. With the addition of other variables there was no meaningful change (R^2 values from the other models ranged from 0.938 to 0.959). The model with counts only was:

$$\dot{V}O_2 = \text{counts} \cdot 15\ s^{-1}(0.01437) + 9.73$$

The equation was used to determine cutoffs for MVPA and VPA. First, the equation was solved for counts using values of 20 and 30 for $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$). The value of 20 for $\dot{V}O_2$ visually divided the data in the figure between rest/slow walk and brisk walk/jogging (715 counts$\cdot$15 s^{-1}). The $\dot{V}O_2$ of 30 visually divided between rest/slow walk/brisk walk and jogging (1411 counts$\cdot$15 s^{-1}). Although MET levels are often used to determine count cutoffs, they were not used for this study because we are not certain the concept holds true in children this age. Young children have higher RMR than older children and adolescents (5), and it was not appropriate to use the standard adult value or the resting $\dot{V}O_2$ value from this study as 1 MET. Sensitivity and specificity for the MVPA cut-point were 97.2 and 91.7%, respectively. For the VPA cut-point the sensitivity was 98.2% and the specificity was 61.1%.

Cross-validation. The mean $\dot{V}O_2$ during free play was 19.7 $mL \cdot kg^{-1} \cdot min^{-1}$, with mean accelerometer counts of 389 counts$\cdot$15 s^{-1}. Both the accelerometer counts and $\dot{V}O_2$ as estimated from accelerometer counts were skewed. The intraclass correlation coefficient from $\dot{V}O_2$ estimated from accelerometer counts and $\dot{V}O_2$ as measured by the Cosmed was 0.59 using log-transformed data. The Spearman correlation coefficient between the two measures was 0.80 ($P < 0.001$). Percentage of agreement, kappa, and modified kappa for MVPA were 0.73, 0.40, and 0.46, respectively. For VPA, the same measures

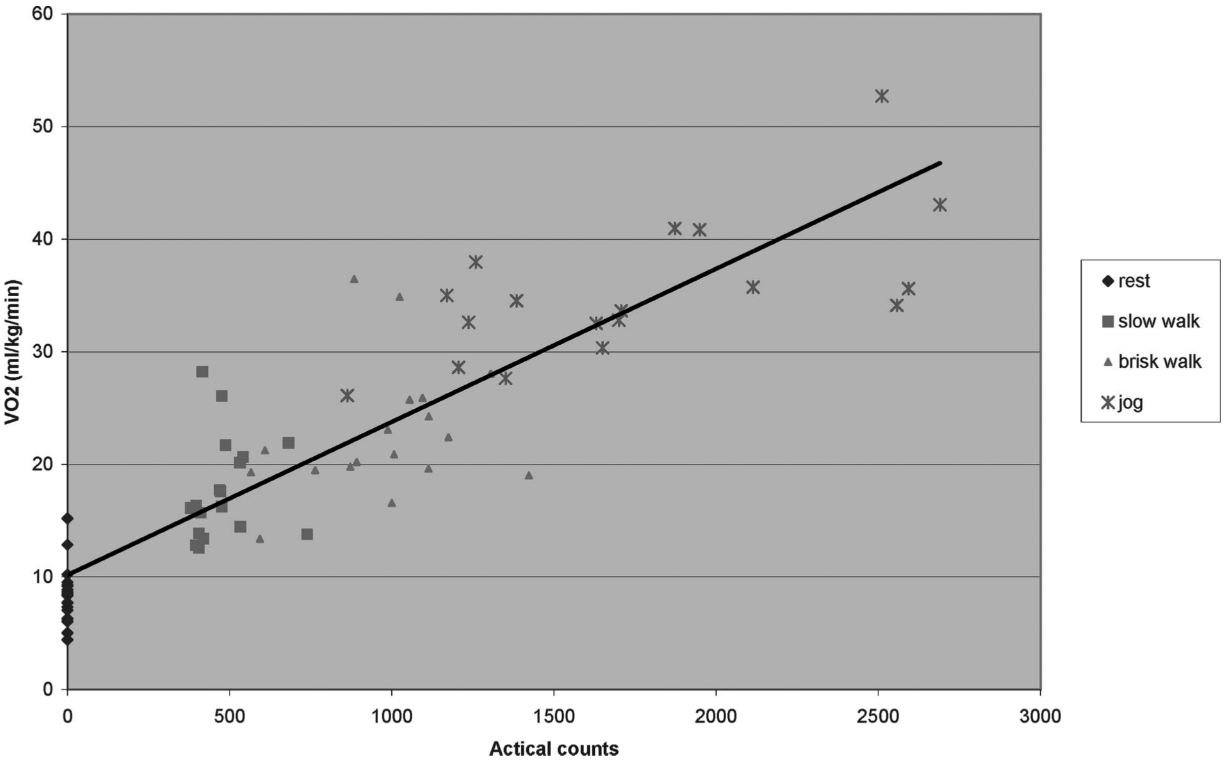

FIGURE 1—Relationship between Actical counts and $\dot{V}O_2$.

of agreement were 0.85, 0.26, and 0.71. To examine the data visually, $\dot{V}O_2$ predicted by the equation was plotted against $\dot{V}O_2$ measured (Fig. 2). It appears that the equation generated using accelerometer counts underpredicted $\dot{V}O_2$ in relation to the measured values.

DISCUSSION

This study is the first to provide calibration and cross-validation data for the Actical accelerometer as a measure of physical activity using a metabolic criterion measure in preschool children. The results indicate that Actical counts are very highly correlated with $\dot{V}O_2$ in 3- to 5-yr-old children who perform structured, weight-bearing physical activities. Count cutoffs for moderate-intensity ($\dot{V}O_2$ = 20 mL·kg^{-1}·min^{-1}) and vigorous-intensity ($\dot{V}O_2$ = 30 mL·kg^{-1}·min^{-1}) physical activity showed satisfactory sensitivity and specificity. When the calibration equation and count cut-points established with structured activities were cross-validated with children performing unstructured activities, accelerometer counts and $\dot{V}O_2$ were still well correlated. Also, there was good agreement between intensity categories as estimated from accelerometer counts and $\dot{V}O_2$ while children performed unstructured activities. These findings indicate that the Actical accelerometer can be used as a measure of physical activity in young children.

It is difficult to compare the results of this study with those of others in the literature. Few studies have calibrated accelerometers, especially in children. Before the current investigation, three calibration studies were conducted in preschool children, (3,14,17), but they all used a different

TABLE 1. $\dot{V}O_2$ and accelerometer counts by activity.

Activity	Variable	Total (N = 18) Mean (SD)
Resting	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	8.4 (2.6)
	Counts	0 (0)
Slow walk	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	17.7 (4.5)
	Counts	479.6 (98.7)
Brisk walk	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	22.8 (5.8)
	Counts	971.1 (234.0)
Jog	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	35.3 (6.3)
	Counts	1746.9 (556.1)

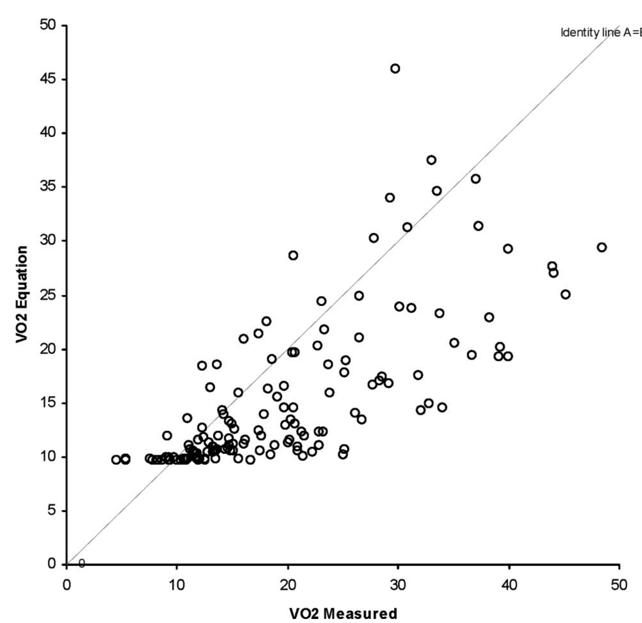

FIGURE 2—Relationship between $\dot{V}O_2$ measured and $\dot{V}O_2$ predicted by equation (using counts) during cross-validation.

criterion measure (direct observation) and different accelerometers (Actigraph, Actiwatch) from that of the current study. Two calibration studies did use metabolic criterion measures to examine the Actical accelerometer (7,13), but both focused on older children and adolescents and did not include young children. Of those two studies, one developed a prediction equation for counts and determined validity against indirect calorimetry ($r = 0.89$, $SEE = 0.06$) (7), with results similar to those of the current investigation. The other study established a prediction equation and count cut-points for both the Actiwatch and Actical using direct calorimetry (13). The cut-points generated for the Actical in that study (1500 counts·min^{-1} for MVPA and 6500 counts·min^{-1} for VPA) were somewhat comparable to the cut-points in the current study (2860 counts·min^{-1} for MVPA and 5644 counts·min^{-1} for VPA) if the 15-s time intervals (epochs) in the current study are multiplied by four. The cut-point values in the current study compare better to previously established values for the Actical than cut-point values that exist among calibration studies for other accelerometers (12,19). However, the difference of at least 1000 counts between cut-points from this study and the Puyau et al. study (12) is enough to cause misclassification of physical activity levels. This is not surprising considering that count cut-points are likely to be different for different age groups.

The current study collected data in 15-s intervals, whereas others involving the Actical used 1-min intervals. Some researchers have indicated that smaller data collection intervals may be useful for young children, because their movements are more sporadic by nature than those of older children and adolescents (1). This difference in data collection interval length raises issues regarding the comparison of studies, because multiplying 15-s counts by four to obtain 1-min values may misrepresent the data. It is possible that data collected via different interval lengths should not be compared, and more research on this issue is needed. However, we are confident that our cut-points can be used for preschool-age children when data are collected in 15-s intervals.

Few studies have included a cross-validation of their accelerometer count cut-points. Because accelerometry is most often applied under free-living conditions, it is important to ensure that cut-points make sense in that context, which was the point of the cross-validation in the current study. We acknowledge that the use of $\dot{V}O_2$ as a criterion measure during free-living activities may have limitations; nonetheless, agreement between measured and predicted $\dot{V}O_2$ in the cross-validation was acceptable. However, more work with accelerometry under free-living conditions is necessary for researchers to better understand the ability of the devices to capture activities of normal daily life.

This study had a few limitations. The equation and count cut-points were created for use in preschool-age children for the Actical accelerometer only. Also, the sample is a small size and predominantly African American, which may limit the ability to generalize findings. However, our previous research has shown no differences between African American and white preschool children in accelerometer counts and $\dot{V}O_2$ (unpublished data, 2005).

Overall, results of the study indicate that the Actical accelerometer is a valid tool for measuring PA in young children. The cut-points created in this study should be used for an epoch length of 15 s. The Actical's small size and water resistance, combined with its validity, make it attractive for use in future, larger scale studies.

We thank Jennifer Grubb and Lauren Hastings for their assistance with data collection, Gaye Groover Christmus for her editorial expertise, and Janna Borden for her project management assistance. We also thank the participants and their parents, as well as the staff from the preschool. Two of the accelerometers used in this study were lent to us by Mini-Mitter.

This project was funded by an ILSI Research Foundation grant and NIH R01 HD043125.

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